Numerical simulation of the vortex dynamics and of the flow control around a simplified ground vehicle

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Abstract: The aim of this work is to better understand the impact of the vortical structures motion to the drag coefficient of a simplified ground vehicle. A theoretical study and numerical experiments show the strong relationship between the distance of the vortices to the back wall and the pressure forces. These pressure forces are also linked to the size of the vortices. So to control the flow it is possible both to change the trajectories of the vortices and to split strong vortices into smaller ones. Numerical results show that the best drag control corresponds to the combination of small vortices and fast removals from the wall.

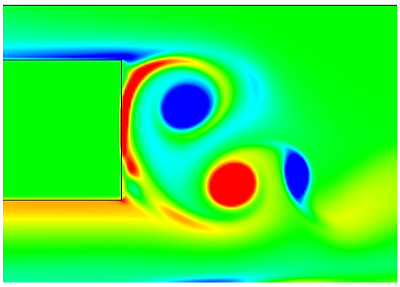
Keywords: Numerical simulation, Drag control, Ahmed body.

1 Study and control of a single vortex

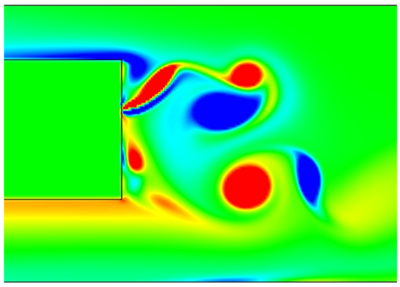
Let H be the height of the back wall of the vehicle characterized in its two dimensional representation by the coordinates set $x = 0$ and $-H/2 \leq z \leq H/2$, let us consider $M(0, z)$ a point on the back wall and a vortex whose center is located at point $P(x_1, z_1)$, $x_1 > 0$. If the vortex is moving, the instantaneous pressure force $F_p(t)$ induced by the vortex on the wall at time t can be evaluated by :

$$F_p(t) = \frac{\rho}{2}\frac{\Gamma^2}{\pi^2}\int_{-\frac{H}{2}}^{+\frac{H}{2}} \frac{x_1^2(t)}{(x_1^2(t) + (z - z_1(t))^2)^2} dz$$

where ρ is the density and Γ is the circulation of the vortex. A numerical simulation is set with a vortex behind the back wall moving both from the bottom to the top along the wall and forward. To control the effect of this vortex on the wall, a constant blowing jet is located at two thirds of the height. When the vortex arrives in front of the jet it is pushed away and so the pressure force decreases (Figure 1). It is remarquable to see that the difference between the uncontrolled and the controlled cases for the theoretical computation of the pressure forces F_p and for the numerical computation of the forces F_{p-comp} using the simulated pressure values on the wall has the same evolution.



(a) uncontrolled case



(b) controlled case

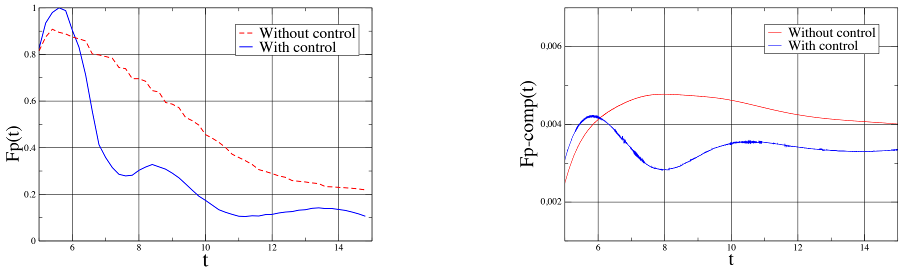


Figure 1: Comparison of the vorticity field in the wake of Ahmed body between the uncontrolled and the controlled cases at the same time (top). History of the theoretical pressure force F_p and of the pressure force computed from the numerical simulation at the back F_{p-comp} induced by the top vortex (bottom).

2 Control of the flow around a simplified ground vehicle

In this study two dimensional simulations are performed as the base flow around bus-shaped bodies have almost a two dimensional behaviour [2]. First of all an active control procedure is applied to control the flow around a simplified vehicle on top of a road using a blowing jet in the middle of the back wall. The result is a strong decrease of the pressure forces at the wall yielding a 20% decrease of the drag coefficient as the vortices coming from the bottom corner remove from the wall linearly with time t instead of t^2 without control. On the other hand a porous layer is added on the roof of the vehicle to control the vortex shedding of the top vortices. At the interface between the porous medium and the fluid Kelvin-Helmholtz instabilites develop and create small eddies that are convected to the back. These eddies induce much lower pressure forces and a 20% decrease of the drag coefficient is obtained. Combining the two control processes a 31% reduction of the drag coefficient is achieved [1].
At the conference the vortex dynamics will be precisely analysed (trajectories, removal speeds from the wall) in both the uncontrolled and the controlled cases. The link between the vortex behaviour and the pressure forces will be emphasized.

References

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